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(54) Sensor position indicator coils to be used in magnetoencephalographic experiments and a means of attaching them to the head.

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**Description**

This invention is about coils used in magnetoencephalographic experiments to determine the position and orientation of the magnetometer, and a means of attaching the said coils to the head. In magnetoencephalography (MEG), the weak magnetic fields elicited by the human brain are measured. The method is gaining gradually a more important role in medical research and diagnostics. In particular, it is possible to investigate the brain functions and disorders in a human being without touching the person or exposing him to electromagnetic radiation or radioactive tracers. In contrast to the widely used electroencephalogram (EEG), in which the electric potential distribution is measured on the surface of the scalp, the magnetoencephalogram suffers far less from distortions caused by inhomogeneities in the conductivity of the human tissue. Therefore, it is possible to locate source currents related to brain activity with a spatial and temporal resolution of a few millimeters and milliseconds. The method has been reviewed in detail, for example, in *CRC Critical Reviews in Biomedical Engineering*, volume 14 (1986), issue 2, pp. 93-126.

Instruments used in MEG should be able to detect magnetic signals whose magnetic flux density is typically 100 fT or less. In addition, the measurement is to be performed simultaneously at several locations; the measurement of even more than one hundred magnetic signals from all over the head is necessary. The only sensor capable of detecting these minute signals is the so-called Superconducting Quantum Interference Device (SQUID) magnetometer. The operation of the device has been explained in detail in an article in *Journal of Low Temperature Physics*, volume 76 (1989), issue 5/6, pp. 287-386.

In order to locate accurately the current distribution caused by the brain's activity from the measured magnetic field distribution, the position and orientation of the magnetometers with respect to the head has to be known. Mechanical means of determining the position and orientation are too elaborate and prone to errors; therefore an automatic position indicator system is needed.

In magnetoencephalographic experiments, one typically uses a locating method employing at least three transmitter coils that are attached to the subject's head; the positions and orientations of the coils are accurately determined prior to the measurement by some other means. The system also includes a current supply, a magnetic field detector, and a computer to determine the coordinates of the coils on the basis of the measured magnetic field. The system is capable of automatically determining the position and orientation of the magnetometer during the measurement. As the magnetic detector of the position indicator system, a multichannel SQUID-magnetometer is particularly useful (cf. *Review of Scientific Instruments*, volume 58 (1987), issue 11, pp. 2145-2156 or *Advances in Biomagnetism*, edited by S. J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Plenum Press, New York 1989, pp. 689-692 and pp. 693-696). Another known position indicator system (US4793355) employs orthogonal coil sets comprising three coils as transmitters and receivers; the method is based on the induction principle. The receiver coils are attached to the head of the subject and the transmitter coils to the magnetometer.

It is crucial for the accuracy of the position indication that the coils stay firmly on their positions during the measurement; it is also important to have them as close to the measurement area as possible. Usually, the coils are wound, by hand or by other means, from wire around a non-magnetic core, as in the references cited above. Three such coils are cast in epoxy resin, forming a coil set. The coil sets are attached to the subject's head by means of a flexible headband or with adhesive tape.

The main drawback of the prior-art technique is that the coil sets are too big to be attached to the actual measurement area, i.e. between the head and the SQUID magnetometer. On the other hand, the present techniques do not provide a possibility to attach the coils firmly at an arbitrary position on the cortex. When using a headband, the area where the attachment of the coils is possible is limited, and the hair prevents a firm adhering of the coils with tape. The accuracy of dimensions of wire-wound multi-turn coils is not very good, and taking into account the stray fields or eliminating them is very elaborate. The determination of the effective dipole moment of the coil is therefore difficult; the error reflects itself correspondingly in the results of the sensor position determination.

In another contexts, several possible means of attaching the coils to the head have been described. For example, DE-2 206 913 deals with a stiff headband to be placed around the subject's head for attaching EEG electrodes. The headband is hinged on the back, and it is tightened around the head using a punched rubber strap or, alternatively, a spring-loaded hinge. The electrodes are attached to the headband via stiff connector wires. The wires are bent in a spring-like manner to press the electrodes against the head. The solution presented in the said reference has several drawbacks. Due to the completely stiff structure, the construction cannot be made flat enough not to considerably hamper the ease of operation of the magnetometer. As a result, the multichannel mag-

netometer must be placed rather far from the head, resulting in a substantially deteriorated signal-to-noise ratio. In addition, the means of attaching the electrodes (Fig. 1 of the reference cited above) is not suitable for position indicator coils because it utilizes only one support arm: a well-defined position and orientation (along the tangent plane) on the head, accurate enough for the MEG method and stationary during the measurement, cannot be guaranteed; coils may move easily during the measurement, for instance, when moving the magnetometer. A third drawback is that the electrodes can only be attached to certain predetermined positions.

DE-2 124 704 describes an elastic, hollow headband used to attach electrodes. The electrodes are located on the inside surface of the headband, and when the headband is pressurized, e.g., by compressed air the electrodes are pressed against the head of the subject. This is not a solution either, because the construction cannot be made flat enough not to hamper the placing the magnetometer as close to the head as possible. In addition, the electrodes can be attached only to predetermined places.

In EP-A2-0 399 499 magnetometer elements are attached to a stiff shell (cf. Fig. 6 of the reference). The method is not suitable for position indicator coils, since the resulting structure is completely stiff. The coils cannot be attached freely anywhere on the cortex on every subject so that the distance from the magnetometers to the head would not substantially increase. A solution to this problem would be an individual, tight-fitting shell for each subject, but this would certainly considerably annoy the subject. In addition, making individual shells would make clinical measurements with patients more elaborate and increase the time consumption and cost for preparing the measurement excessively.

EP-A3-199 214 mentions two means of attaching electrodes to the subject's head. The first one employs an elastic cap which can be set very tightly against the head. The second method includes a stiff headband which can be tightened around the head. A stiff strip is then attached to this headband in a fixed and stiff manner; this strip goes over the head. Neither of the two methods is suitable for position indicator coils, since the elastic cap does not guarantee that the coils are not moved during the measurement and the stiff construction does not allow a free selection of measurement points on the cortex. The stiff construction is also uncomfortable for the subject.

The use of planar coils, fabricated using thin film or thick film techniques and encapsulating them inside epoxy resin as well as the use of parallel conductors patterned on flexible, insulating substrates is known as such, for example, from DE-A1-3 135 962, DE-C3-2 315 498, US-7 749 946, *IEEE Transactions on Magnetics*, vol. MAG-17, issue 1 (January 1981), pp. 400-401 and DE-A1-3 148 192. None of the features described in the above references solves alone the problem how to make a small, dimensionally accurate coil the stray fields of which are negligible, including current supply leads, and which is, in addition, as flat as possible and can be reliably and easily attached to the head.

With the present invention, a substantial improvement to the prior art is gained. The features heretofore characteristic to this invention are described in claims 1-5.

The most important advantage of the invention is that the position indicator coils can be firmly and easily attached to the head without sacrificing the free choice of the place of attachment or the comfort of the subject. In addition, the coil set can be made so thin that it fits without any trouble between the subject's head and the magnetometer. The fastening strips made of a thin, non-stretching and flexible material, wide enough to prevent lateral movements, guarantee that the coils stay in place during the measurement and firmly press the coils against the head.

The use of planar coils fabricated with thin- or thick film techniques, combined with the use of the headband and the fastening strips, described in claims 1-3, in a common structure is the key to functionality of the concept. The planar coils can be made very thin, and with the use of cast epoxy resin the coils and their necessary contact leads can be encapsulated to protect them mechanically for increased reliability and to attach the coils to the fastening strips. At the same time, the cast epoxy resin can be used to form the small elevations or knobs necessary for supporting the coil element. The fastening strips also include the current supply leads; when the return conductors run symmetrically on both sides of the supply conductor, the stray fields due to them are minimized.

In the following, the invention is described in detail, with reference to the attached drawings. Figure 1 represents the headband portion and Figure 2 the coil portion so that the part against the head is visible. In Figure 3, the geometry of the coil is shown schematically, and Fig. 4 represents the invention attached to the head of the subject.

The headband (1) shown in Fig. 1 is made of fabric or other similar material and its inside has been covered with material, which glides poorly on the skin, e.g. thin foam plastic.

The outside surface of the headband has been covered with material (3) onto which the fastening strips of the coil assembly, shown in Fig. 2, adhere. This can be accomplished using, e.g. commercially

available Velcro™ tape, which has a plurality of small hooks. In addition, the headband has a buckle (4) or another similar device with which the headband is fixed firmly around the head.

The coil assembly, depicted in Fig. 2, comprises the planar coil set (5) attached to at least three long enough fastening strips (6) made of a thin, flexible and inelastic material, e.g. fiber glass. In an alternative embodiment (Fig. 2b) each of the fastening strips has a planar coil set (5) or a separate planar coil (5').

The strips ought to be so thin that they bend easily following the curvature of the head but, at the same time, thick enough to exert a force sufficient to press the coils against the head. In addition, the strips must be wide enough to prevent bending laterally. The underside of the strips has been covered with material (7) adhering to the outside surface of the head band, such as Velcro™ tape. In addition, the coil set has at least three small elevations (8) so that the coil set will settle firmly in the tangent plane of the head, leaning on the knobs (8).

The coil set (5) comprises at least three coils fabricated using thin or thick film techniques. Also, the separate coils (5') have been made with the same methods. Each coil consists of, for example, two spirals laid on top of each other so that the spirals are mirror images. Then, the current can be routed from one spiral to another simply by a via in the insulating material in between. The magnetic fields of the two spirals add to each other, and the stray fields of the conductors can be minimized by having the conductors on top of each other on the substrate plane. Figure 3 shows this situation. The supply leads to the coils should be made as twisted pairs or coaxial cables to minimize stray fields. Especially the embodiment, where the current supply leads have been patterned with a printed-circuit board technique on the fastening strips, is preferable. The stray fields can be minimized in that case so that the middle conductor is symmetrically surrounded by two return conductors. The coils are contacted with the supply leads using, for example, ultrasonic bonding and thin contact wires. The coils with the contacts can finally be encapsulated in epoxy resin or other cast plastics. A coil assembly so fabricated has a thickness of only a few millimeters.

When using the invention, the headband shown in Fig. 1 is first set firmly around the head. Thereafter, the coil assembly is positioned to the desired place and the fastening strips are pressed, following tightly the shape of the head, on the headband. Figure 4 shows the invention attached to the head. The knobs of the coil set, penetrating through hair, are leaning against the head, and to keep the coils firmly in place and oriented in the tangent plane of the head. The properties of the fastening strips described earlier guarantee that the coils are pressed against the head and that the coil set cannot move during the measurement in any direction. Analogously, when removing the coils form the head, the fastening strips are first detached from the headband and thereafter the headband is loosened.

Especially, the fastening strips need not be of equal length. For example, when using three strips one of the strips can be made longer than the others, facilitating the connection to the headband that is most far apart. The strips can be equipped with extensions, too.

## Claims

1. Sensor position indicator coils, to be used in magnetoencephalographic experiments, and a means of attaching them to a subject's head, including a separate, thin headband (1), which is fixable around the head of the subject with a buckle (4) or another similar device, and adapts well to the shape of the head, **characterized in that** on the headband (1) are attached by means of at least three thin, flexible but non-stretchable fastening strips (6), a planar coil set (5), possible to place at an arbitrary desired position on the head, or several single planar coils or coil sets (5') attached to the fastening strips, the said coils (5) or coil sets (5') being manufactured using thin or thick film depositing and patterning techniques or printed circuit patterning methods and so that the outer surface of the head band (1) and the surfaces (7) of the fastening strips leaning on the head are covered with lining materials which stick firmly onto each other, the connection, however, being easily separable.

2. Sensor position indicator coils and a means of attaching them to the head according to claim 1, **characterized in that** the fastening strips (6) are so thin that they bend along the surface of the head but thick enough to exert a force that presses the coil set (5) against the head and that the fastening strips (6) are wide enough to prevent bending in lateral direction.

3. Sensor position indicator coils and a means of attaching them to the head according to claim 1 or 2, **characterized in that** the coils (5, 5') and their electrical contacts to the current supply leads and the ends of the fastening strips, facing the coils, are encapsulated in cast plastics.

4. Sensor position indicator coils and a means of attaching them to the head according to claim 3, **characterized in that** the under side of the coil set (5) contains at least three small elevations (8) so that the coil set settles on a surface of a sphere, leaning on the said small elevations, in a plane equal to the tangent plane of the said sphere when pressed against the sphere by the fastening strips (6).

5. Sensor position indicator coils and a means of attaching them to the head according to claim 1, 2, 3, 4 or 5, **characterized in that** the fastening strips (6) have been made of printed circuit board where the conductors for supplying current to the coils have been patterned so that the said conductors on the said strips comprise a center conductor surrounded symmetrically by return conductors in order to minimize stray fields.

**Patentansprüche**

1. Vorrichtung mit Spulen zur Anzeige der Position eines Sensors zur Verwendung bei magnetoenzephalographischen Experimenten mit Mitteln zum Befestigen der Spulen am Kopf einer Person mit Hilfe eines gesonderten dünnen Kopfbandes (1) mit einer Schnalle (4) oder dgl., das um den Kopf gelegt und befestigt werden kann und das sich gut der Kopfform anpaßt,
**dadurch gekennzeichnet,**
daß am Kopfband (1) mit Hilfe von wenigstens drei dünnen, biegsamen, aber nicht dehnbaren, streifenförmigen Befestigungsbändern (6) ein Satz (5) ebener Spulen befestigt ist, der in einer beliebigen Position am Kopf placiert werden kann, oder auch mehrere einzelne planare Spulen oder Spulensätze (5'), die an den Befestigungsbändern vorgesehen sind, wobei die Spulen (5) oder die Spulensätze (5') mit Hilfe der Dünnschichttechnik, Dickschichttechnik, Mustertechnik oder Schaltungsdrucktechnik hergestellt worden sind, und zwar derart, daß die Außenfläche des Kopfbandes (1) und diejenigen Flächen (7) der Befestigungsstreifen, die am Kopf anliegen, mit einer Beschichtung versehen sind, die fest anhaftet, wobei die Verbindung aber leicht getrennt werden kann.

2. Vorrichtung nach Anspruch 1,
**dadurch gekennzeichnet,**
daß die Befestigungsstreifen (6) so dünn sind, daß sie längs der Oberfläche des Kopfes gebogen werden können, aber dennoch dick genug, um eine Kraft auszuüben, die den Spulensatz (5) gegen den Kopf drückt, und daß die Befestigungsstreifen (6) breit genug sind, um ein Verbiegen in seitlicher Richtung zu verhindern.

3. Vorrichtung nach Anspruch 1 oder 2,
**dadurch gekennzeichnet,**
daß die Spulen (5, 5') und ihre elektrischen Kontakte zum Anschluß an die Stromversorgungsleiter sowie die Enden der Befestigungsstreifen, die den Spulen gegenüberliegen, in Gießharz eingegossen sind.

4. Vorrichtung nach Anspruch 3,
**dadurch gekennzeichnet,**
daß die Unterseite des Spulensatzes (5) wenigstens drei kleine Erhebungen (8) aufweist, so daß die Spule auf der Oberfläche einer Kugel aufruht, wobei sie sich auf den kleinen Erhebungen abstützt, und zwar in einer Ebene entsprechend der Tangentialebene der Kugel, wenn sie mit Hilfe der Befestigungsstreifen (6) an die Kugel angedrückt werden.

5. Vorrichtung nach einem der vorhergehenden Patentansprüche,
**dadurch gekennzeichnet,**
daß die Befestigungsstreifen (6) aus bedruckten Schaltungsmaterial hergestellt sind, wobei die Leiter für die Stromzufuhr zu den Spulen ebenfalls gedruckt worden sind, so daß die Leiter an den Streifen einen mittleren Leiter aufweisen, der symmetrisch von Rückführleitern umgeben ist, um Streufelder zu minimieren.

**Revendications**

1. Bobines d'indication de position de capteurs utilisées pour des examens de magnéto-encéphalographie, et des moyens pour les fixer sur la tête d'un patient, comprenant une bande formant serre-tête (1) mince, indépendante, pouvant être fixée autour de la tête du patient avec une boucle (4) ou un autre dispositif similaire, et s'adaptant bien à la forme de la tête, caractérisés en ce qu'il est fixé sur le serre-tête (1), au moyen d'au moins trois courroies d'attache minces, souples mais non étirables (6), un jeu de bobines planaires (5) qu'il est possible de placer dans une position arbitraire souhaitée sur la tête, ou une pluralité de bobines planaires individuelles ou jeux de bobines (5') fixés sur les courroies d'attache, lesdites bobines (5) ou les jeux de bobines (5') étant fabriqués en utilisant des techniques de dépôt et de dessin en film mince ou épais ou des procédés de dessin de circuits imprimés et de manière que la surface extérieure du

serre-tête (1) et les surfaces (7) des courroies d'attache portant sur la tête soient recouvertes de matériaux de revêtement adhérant fermement l'un sur l'autre, la jonction étant toutefois facilement séparable.

2. Bobines d'indication de position de capteurs et moyens pour les fixer sur la tête selon la revendication 1, caractérisés en ce que les courroies d'attache (6) sont suffisamment minces pour pouvoir être courbées sur la surface de la tête, mais suffisamment épaisses pour exercer une force qui presse le jeu de bobines (5) contre la tête et en ce que les courroies d'attache (6) sont suffisamment large pour éviter la courbure dans la direction latérale.

3. Bobines d'indication de position de capteurs et moyens pour les fixer sur la tête selon la revendication 1 ou 2, caractérisés en ce que les bobines (5, 5') et leurs contacts électriques sur les fils d'alimentation en courant et les extrémités des courroies d'attache, tournées face aux bobines, sont enrobées dans une matière plastique moulée.

4. Bobines d'indication de position de capteurs et moyens de les fixer sur la tête selon la revendication 3, caractérisés en ce que la face inférieure du jeu de bobines (5) contient au moins trois petites saillies (8) de manière que le jeu de bobines soit disposé sur la surface d'une sphère, en prenant appui sur lesdites petites saillies, dans un plan égal au plan tangent à ladite sphère lorsqu'il est pressé contre la sphère par les courroies d'attache (6).

5. Bobines d'indication de position de capteurs et moyens pour les fixer sur la tête selon les revendications 1, 2, 3, 4 ou 5, caractérisés en ce que les courroies d'attache (6) ont été constituées par une plaquette de circuit imprimé dans laquelle la configuration des conducteurs d'alimentation en courant des bobines a été agencée de manière que lesdits conducteurs sur lesdites courroies comprennent un conducteur central entouré symétriquement par des conducteurs de retour pour limiter au minimum les champs parasites.

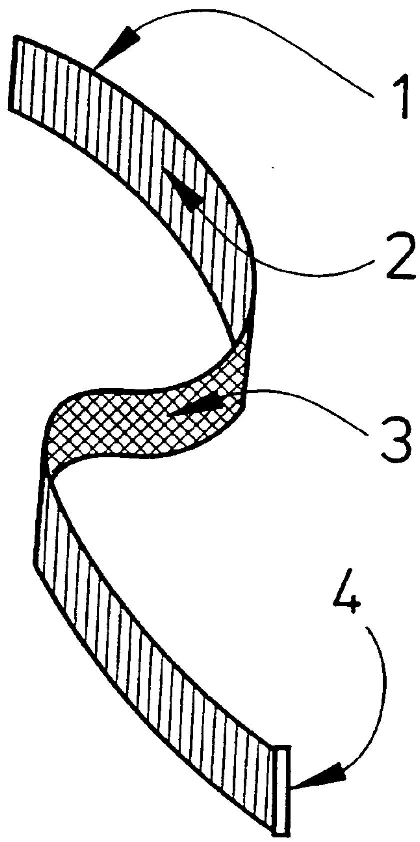


Figure 1

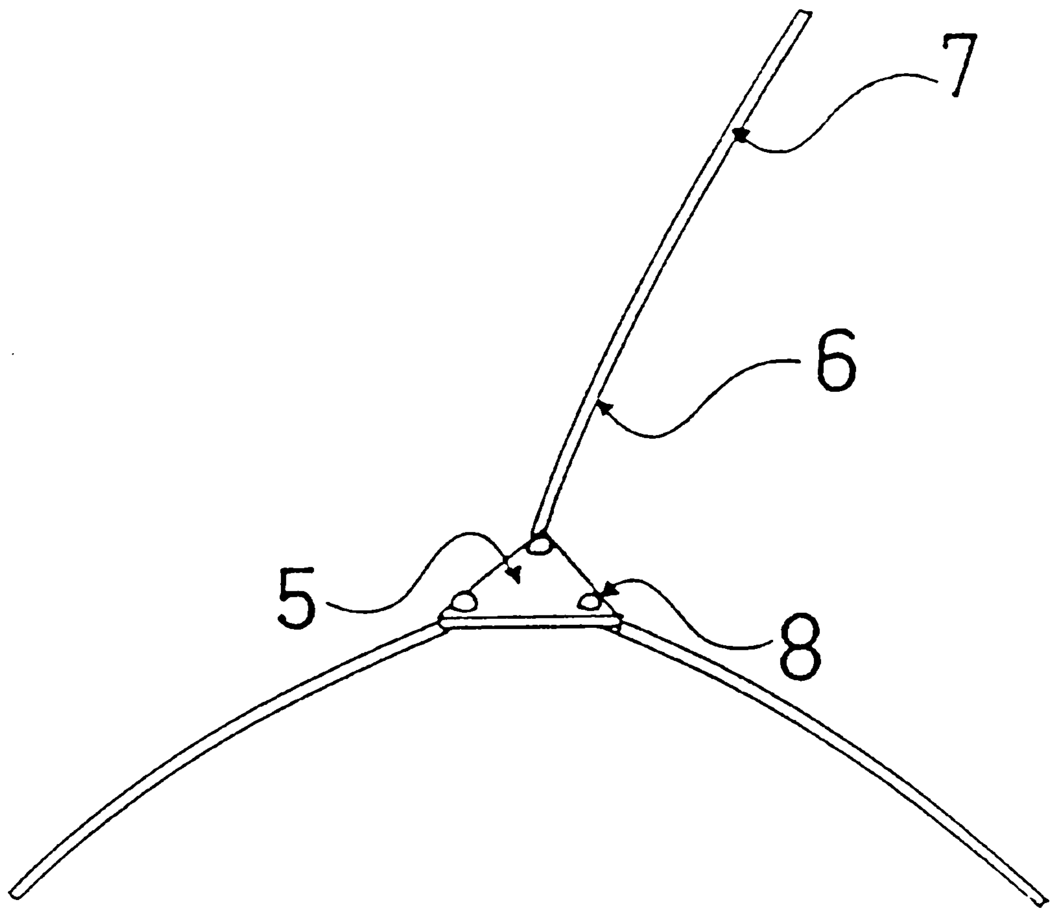


Figure 2a

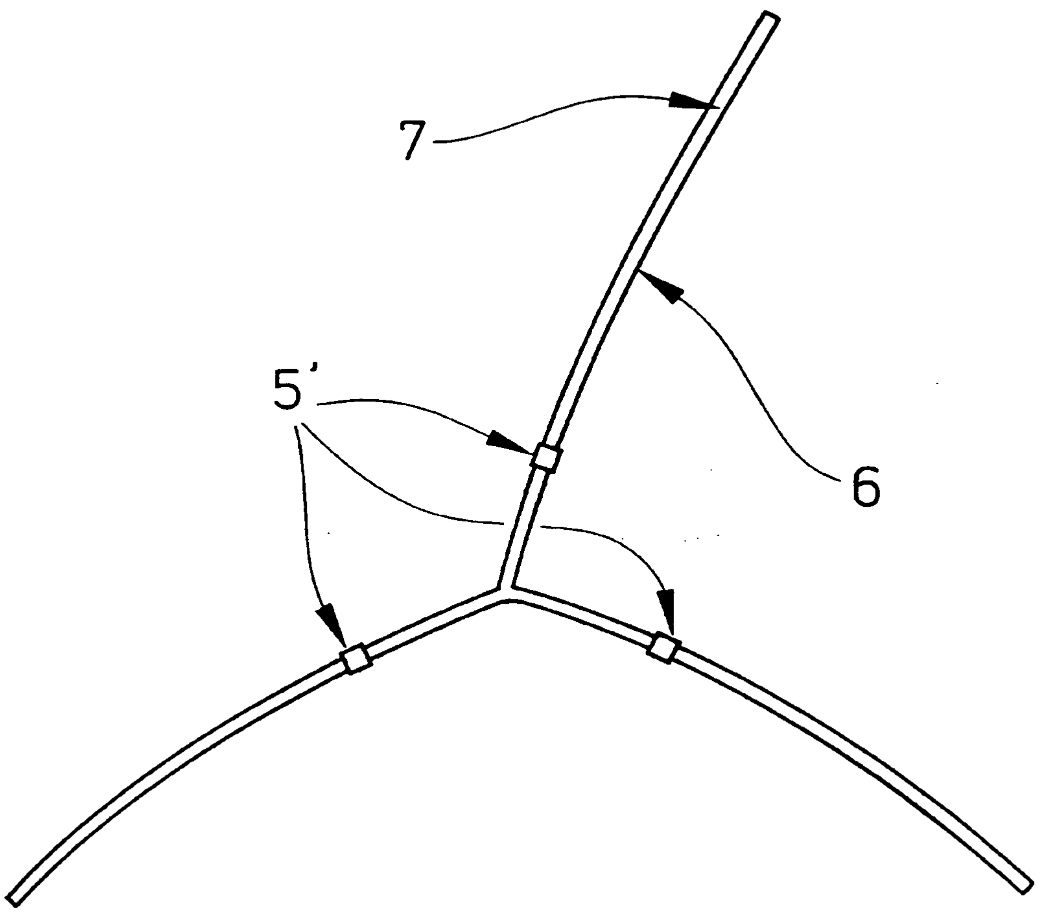


Figure 2b

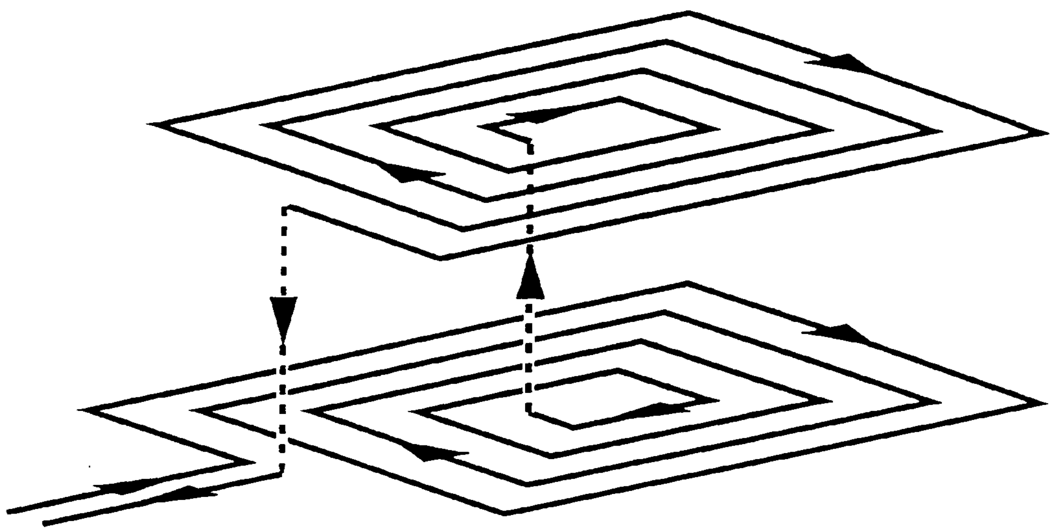

Figure 3

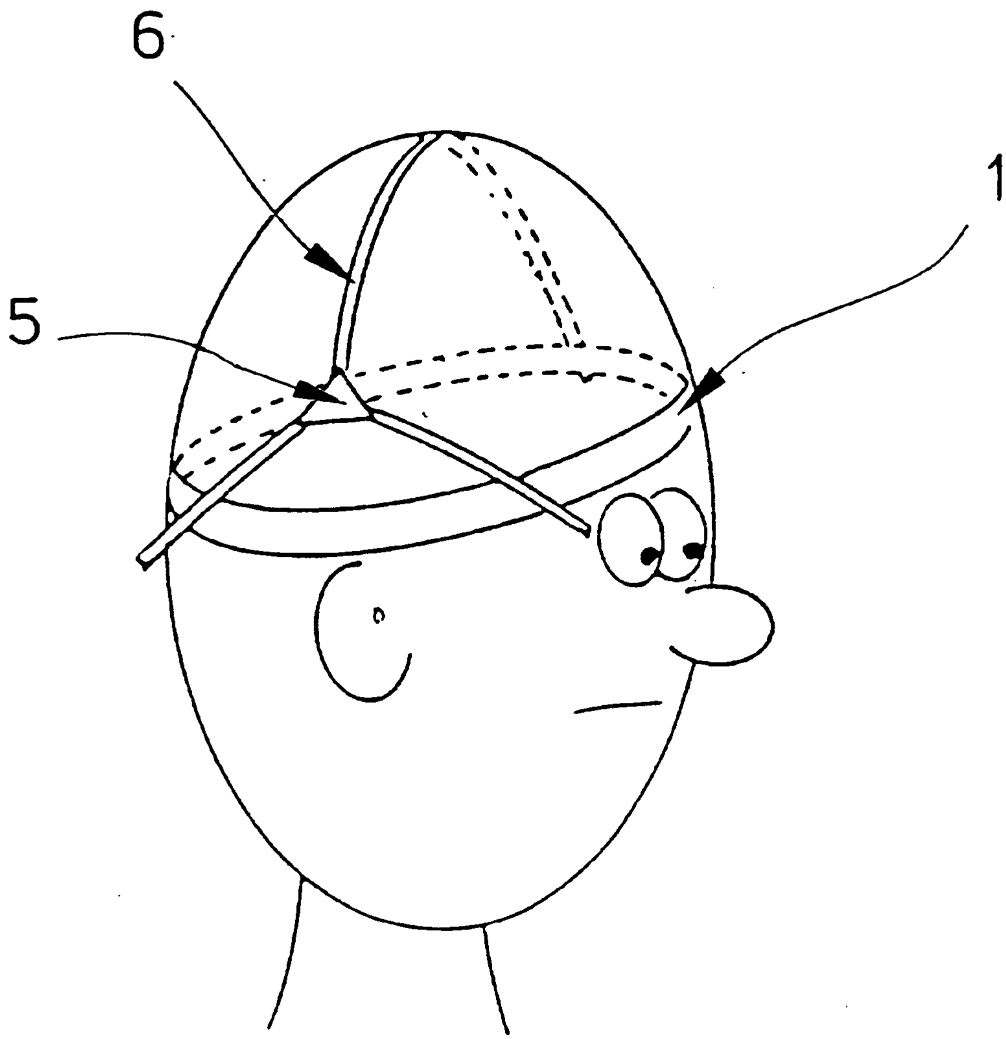


Figure 4